

Lilibeth Carola Leyton Mendoza

**Características físicas e mecânicas de materiais resinosos utilizados para
restauração de dentes tratados endodonticamente usando dois protocolos de
fotoativação**

*Physic mechanical characterization of resin-based materials used for restoring
endodontic treated teeth under two light activation protocols*

Dissertação apresentada à Faculdade de Odontologia da
Universidade Federal de Uberlândia como requisito parcial
para obtenção do título de Mestre em Odontologia na Área
de Clínica Odontológica Integrada.

Uberlândia, 2023

Lilibeth Carola Leyton Mendoza

Características físicas e mecânicas de materiais resinosos utilizados para restauração de dentes tratados endodonticamente usando dois protocolos de fotoativação

Physic mechanical characterization of resin-based materials used for restoring endodontic treated teeth under two light activation protocols

Dissertação apresentada à Faculdade de Odontologia da Universidade Federal de Uberlândia como requisito parcial para obtenção do título de Mestre em Odontologia na Área de Clínica Odontológica Integrada.

Orientador: Prof^o. Dr^o. Carlos José Soares

Banca examinadora:

Prof^o. Dr^o. Carlos José Soares

Prof^a. Dr^a. Gisele Rodrigues da Silva

Prof^a. Dr^a. Andrea Dolores Valdivia

Suplentes

Profa. Dra. Laís Rani Sales Oliveira

Prof. Dr. Flávio Domingues das Neves

Uberlândia, 2023



UNIVERSIDADE FEDERAL DE UBERLÂNDIA
 Coordenação do Programa de Pós-Graduação em Odontologia
 Av. Pará, 1720, Bloco 4L, Anexo B, Sala 35 - Bairro Umuarama, Uberlândia-MG, CEP 38400-902
 Telefone: (34) 3225-8115/8108 - www.pgoufu.com - copod@umuarama.ufu.br



ATA DE DEFESA - PÓS-GRADUAÇÃO

Programa de Pós-Graduação em:	Odontologia				
Defesa de:	Dissertação de Mestrado Acadêmico, nº 424, PPGDONT				
Data:	Quatorze de Julho de Dois Mil e Vinte e Três	Hora de início:	11:00	Hora de encerramento:	[13:20]
Matrícula do Discente:	12122ODO002				
Nome do Discente:	Lilibeth Carola Leyton Mendoza				
Título do Trabalho:	Características físicas e mecânicas de materiais resinosos utilizados para restauração de dentes tratados endodonticamente usando dois protocolos de fotoativação				
Área de concentração:	Clínica Odontológica Integrada				
Linha de pesquisa:	Biomecânica Aplicada à Odontologia				
Projeto de Pesquisa de vinculação:	Biomecânica Aplicada à Odontologia				

Reuniu-se em Web Conferência pela plataforma Zoom, em conformidade com a PORTARIA Nº 36, DE 19 DE MARÇO DE 2020 da COORDENAÇÃO DE APERFEIÇOAMENTO DE PESSOAL DE NÍVEL SUPERIOR - CAPES, pela Universidade Federal de Uberlândia, a Banca Examinadora, designada pelo Colegiado do Programa de Pós-graduação em Odontologia, assim composta: Professores Doutores: Andréa Dolores Correia Miranda Valdivia (UNIVERSIDAD AUTÓNOMA DE GUADALAJARA); Gisele Rodrigues da Silva (UFU); Carlos José Soares (UFU); orientador(a) do(a) candidato(a).

Iniciando os trabalhos o(a) presidente da mesa, Dr(a). Carlos José Soares, apresentou a Comissão Examinadora e o candidato(a), agradeceu a presença do público, e concedeu ao Discente a palavra para a exposição do seu trabalho. A duração da apresentação do Discente e o tempo de arguição e resposta foram conforme as normas do Programa.

A seguir o senhor(a) presidente concedeu a palavra, pela ordem sucessivamente, aos(as) examinadores(as), que passaram a arguir o(a) candidato(a). Ultimada a arguição, que se desenvolveu dentro dos termos regimentais, a Banca, em sessão secreta, atribuiu o resultado final, considerando o(a) candidato(a):

[A]provado(a).

Esta defesa faz parte dos requisitos necessários à obtenção do título de Mestre.

O competente diploma será expedido após cumprimento dos demais requisitos, conforme as normas do Programa, a legislação pertinente e a regulamentação interna da UFU.

Nada mais havendo a tratar foram encerrados os trabalhos. Foi lavrada a presente ata que após lida e achada conforme foi assinada pela Banca Examinadora.



Documento assinado eletronicamente por **Carlos José Soares, Professor(a) do Magistério Superior**, em 14/07/2023, às 13:24, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do [Decreto nº 8.539, de 8 de outubro de 2015](#).



Documento assinado eletronicamente por **Gisele Rodrigues da Silva, Professor(a) do Magistério Superior**, em 14/07/2023, às 13:25, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do [Decreto nº 8.539, de 8 de outubro de 2015](#).



Documento assinado eletronicamente por **Andréa Dolores Correia Miranda Valdivia, Usuário Externo**, em 14/07/2023, às 13:26, conforme horário oficial de Brasília, com fundamento no art. 6º, § 1º, do [Decreto nº 8.539, de 8 de outubro de 2015](#).



A autenticidade deste documento pode ser conferida no site https://www.sei.ufu.br/sei/controlador_externo.php?acao=documento_conferir&id_orgao_acesso_externo=0, informando o código verificador **4647812** e o código CRC **45585AED**.

Ficha Catalográfica Online do Sistema de Bibliotecas da UFU
com dados informados pelo(a) próprio(a) autor(a).

M539 2023	Mendoza, Lilibeth Carola Leyton, 1989- Características físicas e mecânicas de materiais resinosos utilizados para restauração de dentes tratados endodonticamente usando dois protocolos de fotoativação [recurso eletrônico] : Physic mechanical characterization of resin-based materials used for restoring endodontic treated teeth under two light-activation protocols / Lilibeth Carola Leyton Mendoza. - 2023. Orientadora: Carlos José Soares. Dissertação (Mestrado) - Universidade Federal de Uberlândia, Pós-graduação em Odontologia. Modo de acesso: Internet. Disponível em: http://doi.org/10.14393/ufu.di.2023.345 Inclui bibliografia. Inclui ilustrações. 1. Odontologia. I. Soares, Carlos José, 1965-, (Orient.). II. Universidade Federal de Uberlândia. Pós-graduação em Odontologia. III. Título. CDU: 616.314
--------------	--

Bibliotecários responsáveis pela estrutura de acordo com o AACR2:
Gizele Cristine Nunes do Couto - CRB6/2091
Nelson Marcos Ferreira - CRB6/3074

DEDICATÓRIA

A Deus por me guiar nesta caminhada. Que na sua infinita bondade permitiu que eu concluísse mais uma etapa da minha jornada. Que nos momentos de aflição me acalentou e acalmou meu coração. Agradeço ainda por ter colocado em minha vida pessoas incríveis que sem as quais não conseguiria chegar até aqui.

Aos meus pais, Victor Franz Leyton Laura e Maria Eulalia Mendoza Ferrufino, sem a força e amor que vocês me dão nada disso seria possível atualmente. Por todo o zelo e dedicação todos os dias. Obrigado por participarem e me ajudarem nessa jornada. Por serem meus grandes exemplos de amor, superação, determinação, perseverança, profissionalismo, dedicação, coragem, simplicidade, humildade, bondade e alegria. Pelos conselhos que fizeram com que pudesse ser cada dia mais forte. Vocês são tudo para mim

Aos meus irmãos Mauricio e Vivian, minha cunhada Yuseli e minha pequena sobrinha Agustina, por ser meus parceiros de vida meus, cúmplices em tantas lindas aventuras que vivemos juntos, obrigada pela sua paciência quando tinha que estudar e deixar mais um pouco de serviço, foi muito difícil ficar longe de vocês, de nossos pais da minha amada Bolívia, mas sempre senti sua presença em alma e coração.

A meu namorado, Thiago Silva Peres, por ser sempre paciente e carinhoso. Obrigado por me acompanhar todos os dias nos quais tive que me dedicar até o final do dia a realização do meu trabalho no CPbio. Obrigado pelos seus conselhos diários, sua doçura e amor contínuo, por ser meu grande parceiro não só de pesquisa mais de vida, aventura, luta, pelo capricho que tem para cuidar de mim e nossa amada Sophia Isabella, que está em caminho. Muchas gracias, amor de mi vida, por hacerme tan feliz y por crear un hermoso hogar para nosotras. Você faz meus dias mais felizes com seu jeito de alegre, sorridente., puro e transparente. É como você disse calma vai dar tudo certo.

AGRADECIMENTOS

Ao meu orientador Prof. Dr. Carlos José Soares, por acreditar na minha capacidade. O senhor é um grande exemplo de pessoa, profissional e pesquisador para mim. Vejo todos os dias o seu esforço para ser cada dia melhor e tornar tudo todos a sua volta em pessoas melhores e bem-sucedidas. Por isso tenho grande admiração em todos seus ensinamentos passados e busco sempre aprender mais com o senhor todos os dias. Obrigada pela sua orientação e por tudo que você me proporcionou durante o mestrado. Sou muito grato e tenho um carinho enorme por você e pela Professora Priscilla.

Aos amigos, Maria Tereza, Calebe, e Isaac por estarem sempre presentes e por não negarem esforços para me ajudar. Obrigada pelos momentos de descontração, pelas conversas boa e por me ensinarem tanto e me acompanhar nesta caminhada.

Ao grupo BIAOR, ao qual me orgulho de fazer parte. Obrigada por contribuírem com meu aprendizado.

Aos professores do programa de Pós-graduação em Odontologia da UFU (PPGO/UFU), pessoas dedicadas as quais não medem esforços em compartilhar seus conhecimentos. Sou muito grata por ter tido professores tão competentes.

A OEA e GCUB, pela bolsa de estudo e a oportunidade de sair de meu país e me formar como mestre.

À Faculdade de Odontologia da UFU, onde me torno mestre. Sou eternamente grata e tenho imenso orgulho em falar que sou formado nesta casa.

Ao CPbio, lugar ao qual o trabalho se tornou possível pela estrutura física e conforto que proporciona aos alunos.

Ao CNPq, pela bolsa de estudo que me proporcionou apoio financeiro durante esse tempo.

SUMÁRIO

RESUMO/PALAVRAS-CHAVE	9
ABSTRACT/KEYWORDS	11
1. INTRODUÇÃO E REFERÊNCIAL TEÓRICO	12
2. CAPÍTULO 1/ARTIGO 1	14
REFERÊNCIAS	49

RESUMO

O tipo de cimento resinoso e o protocolo de fotoativação da luz podem influenciar as propriedades mecânicas da cimentação de pino e reconstrução do núcleo para restaurar dentes tratados endodonticamente. Este estudo avaliou as propriedades mecânicas influenciadas pela fotoativação imediata ou após 5-minutos de diferentes materiais resinosos utilizados para cimentação de pino de fibra de vidro (cimentos duais ou resinas compostas core) e reconstrução do núcleo (resina bulk-fill ou resinas compostas core). Materiais e Métodos: Nove materiais resinosos foram testados, sendo 4 resinas compostas core: Allcem Core, FGM; LuxaCore Z, DMG; Rebilda DC, VOCO; Clearfil DC Core Plus, Kuraray; 3 cimentos dual: RelyX Universal, 3M Oral Care; RelyX U200, 3M Oral Care; Allcem Dual, FGM; e 2 resinas compostas bulk-fill (RCBs): Opus Bulk Fill APS, FGM; e Filtek One Bulk Fill, 3M Oral Care. Os cimentos duais e as resinas compostas core foram fotoativados usando dois protocolos: imediato e após 5 minutos. Foram medidas a contração pós-gel (Shr, %), resistência flexural (FS, MPa), módulo de elasticidade (E, MPa), resistência à tração diametral (DTS, MPa), resistência à compressão (CS, MPa), dureza Knoop (KH, N/mm²), grau de conversão (DC, %), profundidade de cura (DoC, mm), análise termogravimétrica (TGA, % de conteúdo de carga), radiodensidade. Microscopia eletrônica de varredura (MEV) e espectroscopia por energia dispersiva (EDS) foram utilizadas para avaliar a morfologia e o conteúdo de carga. O resíduo dos cimentos duais e resinas compostas core que permaneceram na ponta automistura foram pesados. Os dados de Shr, TGA, FS, E, DTS, CS, DoC e radiopacidade foram submetidos à análise de 2-way ANOVA e análise de 2-way medidas repetidas ANOVA para KH e DC, seguido do teste de Tukey para identificar diferenças entre os grupos ($\alpha = 0,05$). Resultados: A fotoativação após 5-minutos reduziu significativamente a Shr de todos os cimentos duais e resinas compostas core ($p < 0,001$). O aumento da profundidade reduziu significativamente os valores de KH para todos os materiais ($p < 0,001$). As RCBs e as resinas compostas core apresentaram valores de KH mais altos do que os cimentos duais ($p < 0,001$). A fotoativação após 5-minutos reduziu significativamente os valores de Shr e não teve efeito negativo ou de melhora nas propriedades mecânicas testadas. Os cimentos duais e as resinas compostas core apresentaram maior profundidade de cura do que as RCBs. Os cimentos resinosos core

apresentaram valores de KH mais altos do que os cimentos duais e propriedades mecânicas similares às RCBs.

PALAVRAS-CHAVE: propriedades mecânicas, propriedades físicas, resinas compostas core, cimento resinoso dual, resinas compostas bulk-fill, contração pós-gel, radiopacidade, fotoativação.

ABSTRACT

The resin-based material type and the light activation protocol can influence the mechanical properties of the post cementation and core reconstruction for restoring endodontic treated teeth. This study evaluated the mechanical properties influenced by immediate or 5-minutes delayed light activation of different resin-based materials to cement fiberglass post (dual-cure resin cements or dual-cure resin-core) and to build the core (bulk-resin RBCs or dual-cure resin-core). Nine resin-based materials were tested: 4 dual-cure resin-core: Allcem Core, FGM; LuxaCore Z, DMG; Rebilda DC, VOCO; Clearfil DC Core Plus, Kuraray; 3 dual-cure resin cements: RelyX Universal, 3M Oral Care; RelyX U200, 3M Oral Care; Allcem Dual, FGM; and 2 bulk-fill resin-based composites (RBCs): Opus Bulk Fill APS, FGM; and Filtek One Bulk Fill, 3M Oral Care. The dual-cure materials were light-activated using two protocols: immediate and 5minutes delayed. The post-gel shrinkage (Shr, %), flexural strength (FS, MPa), elastic modulus (E, MPa), diametral tensile strength (DTS, MPa), compressive strength (CS, MPa), Knoop hardness (KH, N/mm²), degree of conversion (DC, %), depth of cure (DoC, mm), thermogravimetric analysis (TGA, % filler content), radiodensity, were measured. Scanning electric microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to evaluate the filler content morphology. The residue of the materials that remained into the automix tip was weighted. Shr, TGA, FS, E, DTS, CS, DoC, and radiopacity data were submitted to 2-way ANOVA; KH and DC were submitted to 2-way repeated measures ANOVA followed by Tukey test ($\alpha = .05$). Delayed light activation reduced significantly the Shr for all dual-cure materials ($p < .001$). Increasing depth significantly reduced the KH values for all materials ($p < .001$). Bulk-fill RBCs and resin-core materials had higher KH values than dual-cure resin cements ($p < .001$). Delayed light activation maintained or increased the KH for dual-cure materials. Bulk-fill RBCs had significantly lower DoC than dual-cure materials ($p < .001$). Delayed light activation reduced significantly the Shr values and had no negative or improvement effect on the tested mechanical properties. Dual-cure resin-based materials had higher DoC than bulk-fill RBCs. Resin-core materials had higher KH values than dual-cure resin cements and similar mechanical properties of RBCs.

KEYWORDS: mechanical properties, physic properties, resin-core materials, dual-cure resin cement, bulk-fill resin-based composite, post-gel shrinkage, radiopacity, light activation.

1. INTRODUÇÃO E REFERÊNCIAL TEÓRICO

Restaurações estéticas têm se tornado cada vez mais populares.(Ferrari *et al.*, 2022) Dentre estes procedimentos restauradores estéticos diversos são realizados em dentes tratados endodonticamente.(de Kuijper *et al.*, 2021) A indicação de pinos de fibra de vidro e materiais restaurador para reabilitar dentes tratados endodonticamente está relacionada à vários fatores, como quantidade e qualidade de estrutura dentária remanescente, presença de férula, e restauração final planejada.(Soares *et al.*, 2018) A resistência de dentes tratados endodonticamente reabilitados com pinos podem ser influenciadas pela dimensão da estrutura até a crista óssea e possibilidade de definição de férula para garantir a integridade funcional.(Kumar *et al.*, 2020) Porém, mesmo na ausência de férula, a indicação de reconstrução coronária indicando pinos e reconstrução com material resinoso pode viabilizar a manutenção de dentes fragilizados. (Barcelos *et al.*, 2017) Na reabilitação o posicionamento do dente no arco, as cargas oclusais que os materiais e dente estão envolvidos, o tipo de restauração se direta ou indireta, o tipo de material, os hábitos do paciente e a habilidade do profissional podem também influenciar a distribuição de tensões. (Nahar *et al.*, 2020)

Os cimentos resinosos core de dupla ativação denominados são indicadas para, concomitantemente proceder a cimentação de pinos de fibra de vidro, executar a reconstrução coronária e ainda para cimentação de coras indiretas. (Reis *et al.*, 2020) A retenção dos pinos de fibra e a resistência da reconstrução coronária está associada à resistência mecânica do material restaurador. Adequada polimerização em profundidade na raiz e a integração adesiva com a dentina radicular determinam o comportamento biomecânico desejado. (Pereira *et al.*, 2015) Não há consenso em relação à superioridade de um cimento resinoso dual convencional em relação às resinas compostas core. (Skupien *et al.*, 2016)

A geração de tensões no interior do canal radicular, e as propriedades mecânicas dos cimentos resinosos duais podem ser influenciados pelo modo de ativação realizado pelo profissional.(Soares *et al.*, 2021) Aguardar 5-minutos após a manipulação para aplicação da luz tem mostrado ser eficiente para minimizar as tensões geradas e melhorar a integridade adesiva para cimentos resinosos duais convencionais.(Soares *et al.*, 2021)

Porém, no limite do nosso conhecimento, não há na literatura informações se esse achado também se aplica a resina composta core de dupla ativação.(Säilynoja et al., 2021)

Portanto, esse trabalho tem por objetivo avaliar propriedades físicas e mecânicas de diferentes tipos materiais usados em duas diferentes estratégias para reabilitar dentes tratados endodonticamente, se pelo emprego de resinas compostas core para cimentar pinos de fibra de vidro e de resina compostas bulk-fill para reconstruir o núcleo coronário, ou o uso concomitante de resinas compostas core de dupla ativação; sob influência de dois métodos de fotoativação se imediata ou tardia (após 5-minutos). Para isso vamos utilizar associação de diferentes ensaios físicos e mecânicos, os quais darão padrão para comparar materiais que já são utilizados para a reconstrução de dentes tratados endodonticamente.

2. CAPÍTULO 1

ARTIGO 1

Physic mechanical characterization of resin-based materials used for restoring endodontic treated teeth under two light activation protocols

***Artigo a ser enviado para o periódico Journal of Prosthetic Dentistry**

Physico-mechanical characterization of resin-based materials used for restoring endodontic treated teeth under different light activation protocols

Lilibeth Carola Leyton Mendoza¹, Thiago Silva Peres², Isaac Daniel Gonzaga Estevão³, Maria Tereza Hordones Ribeiro⁴, Calebe de Melo⁵, Hugo Lemes Carlos⁶, Carlos José Soares⁷

¹ DDS, MSc student, School of Dentistry, UFU – Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, e-mail: carolaleytonm@gmail.com, ORCID: 0000-0003-16084299

² DDS, MSc, PhD student, School of Dentistry, UFU – Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, e-mail: thiagosilvaperes13@hotmail.com, ORCID: 0000-0002-8988-2614

³ Undergraduate Student, School of Dentistry, UFU - Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, e-mail: isaacdgonzaga@gmail.com , ORCID: 0000-0002-3977-8421

⁴ DDS, MSc, PhD student, Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia (UFU), Uberlândia, MG, Brazil, email: mthribeiro.tete@gmail.com, ORCID: 0000-0002-5126-7931

⁵ DDS, MSc student, Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia (UFU), Uberlândia, MG, Brazil, e-mail: calebe@gmail.com, ORCID: 0000-0003-3263-5951

⁶ DDS, MSc, PhD, Professor at Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia (UFU), Uberlândia, MG, Brazil, e-mail: hugocarlo@yahoo.com ORCID: 0000-0002-5111-7781

⁷ DDS, MSc, PhD, Professor at Department of Operative Dentistry and Dental Materials, Dental School, Federal University of Uberlândia (UFU), Uberlândia, MG, Brazil, e-mail: carlosjsoares@ufu.br; ORCID: 0000-0002-8830-605X

Declarations of interest: none

All authors actively participated in the discussion of the manuscript findings, reviewed and approved the final version of this manuscript.

Acknowledgments

The authors are grateful for the support from CNPq, National Council of Scientific and Technological Development – Grants 406840/2022-9; 311001/2021-1; 422603/2021-0 and FAPEMIG (Foundation for Research Support of the State of Minas Gerais) – Grants APQ-02105-18. This research was carried out at CPBio - Biomechanics, Biomaterials and Cell Biology Research Center from the Federal University of Uberlândia.

Corresponding author:

Dr. Carlos José Soares

Federal University of Uberlândia, School of Dentistry

Avenida Pará, 1720, Bloco 4L, Anexo A, Sala 42, Campus Umuarama

Uberlândia - Minas Gerais – Brazil - CEP 38400-902

Phone: +55 34 3225 8119 / Cell Phone: +55 34 999713472, E-mail:

carlosjsoares@ufu.br

Physic-mechanical characterization of resin-based materials used for restoring endodontic treated teeth under two light activation protocols

ABSTRACT

Statement of the Problem. The resin-based material type and the light activation protocol can influence the mechanical properties of the post cementation and core reconstruction for restoring endodontic treated teeth.

Purpose. This study evaluated the physical and mechanical properties influenced by immediate or 5-minutes delayed light activation protocols of different resin-based materials to cement fiberglass post and to build the core.

Material and Methods. Nine resin-based materials were tested: 4 dual-cure core resin-based materials: Allcem Core, FGM; LuxaCore Z, DMG; Rebilda DC, VOCOC; Clearfil DC Core Plus, Kuraray; 3 dual-cure resin cements: RelyX Universal, 3M Oral Care; RelyX U200, 3M Oral Care; Allcem Dual, FGM; and 2 bulk-fill resin-based composites (RBCs): Opus Bulk Fill APS, FGM; and Filtek One Bulk Fill, 3M Oral Care. The dual cure materials were light activated using 2 protocols: immediate or 5-minutes delayed light activation. The post-gel shrinkage (Shr, %), flexural strength (FS, MPa), elastic modulus (E, MPa), diametral tensile strength (DTS, MPa), compressive strength (CS, MPa), Knoop hardness (KH, N/mm²), degree of conversion (DC, %), depth of cure (DoC, mm), thermogravimetric analysis (TGA, % filler content), radiodensity, were measured. Scanning electric microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to evaluate the filler content morphology. The residue of the resin-based materials that remained in the automix tip was calculated (g - %). Data from Shr, TGA, FS, E, DTS, CS, DoC, and radiopacity, were analyzed using 2-way ANOVA and KH and DC were analyzed using 2-way repeated measures ANOVA, followed by Tukey ($\alpha = .05$).

Results. Delayed light activation reduced significantly the Shr for all dual-cure materials ($p < .001$). Delayed light activation maintained or increased the KH for dual cure resin-based materials. Increasing depth significantly reduced the KH values for all materials ($p < .001$). Bulk-fill RBCs and resin-core materials had higher KH values than dual-cure resin cements ($p < .001$). Bulk-fill RBCs had significantly lower DoC than dual-cure materials ($p < .001$).

Conclusions. Wait for 5-minutes for light activate the dual-cure reduced significantly the Shr, maintaining or not influencing negatively all tested physical and mechanical properties. Dual-cure resin-based materials had higher DoC than bulk-fill RBCs. Resin-core materials had higher KH values than dual-cure resin cements and similar mechanical properties of bulk-fill RBCs.

Clinical implications. Resin-core materials had similar or superior physical and mechanical properties than dual-cure resin cements and bulk-fill RBCs, demonstrating to be an alternative to cement fiberglass post, rebuild the core, and cement the final restoration. The 5-minutes delay to light activate the resin-core materials is recommended to reduce the post-gel shrinkage.

INTRODUCTION

The association of a dual-cured resin cement to cement the fiberglass post into the root canal and the coronal reconstruction using resin-based composites has been the option for restoring endodontic treated teeth, with high survival ratio.¹ The alternative for simplifying the restorative procedure, reducing the number of the materials have been stimulate the use dual-cure resin-core material that allows the fiberglass post cementation and core build-up reconstruction at the same time, reducing the number of interfaces and saving time.^{2,3}

Since the introduction of fiberglass posts and core build-up, efforts have been made to improve the bonding properties, mechanical performance, support, and retention to the final restoration.⁴⁻⁶ The mechanical properties of these core materials need to cover all the requirements expected for RBC used for coronal reconstruction and besides present proper polymerization in deep areas of root canal during fiberglass post luting.⁷⁻⁹ The combination of these materials with bonding interaction can created a unique body that allows more homogeneous stress distribution.¹⁰ Proper radiopacity is also a requirement that permit also to detect the adaptation, contact with adjacent teeth, interfacial gaps, and voids presence into the restoration.¹¹⁻¹³ The radiopacity of resin-core materials is scarce in the literature, making necessary to evaluate this property.

For restorations of endodontic treated teeth there are many factors to be considered, like type of resin-based materials, protocols of light activation, and bonding mechanisms that involves optimal mechanical properties.^{14,15}

Usually, clinicians light activate the dual cure materials immediately after the placement into the cavity.^{16,17} However, a delay of 5-minutes between the material mixing and the light activation has been advocated to increase Ph-buffering which is important to permit adequate polymerization.¹⁸ The delayed light activation can also improve mechanical properties such as hardness, elastic modulus, and bond strength, besides reducing the residual shrinkage stress.¹⁹⁻²² However, the influence of the composition of the resin-core material on the physical and mechanical properties, when light activated immediately or after 5-minutes, is also uncertain.²³

Therefore, the aim of this study was to evaluate the mechanical properties of different resin-based materials used for conventional protocol for restoring endodontic treated teeth involving dual-cure resin cement and bulk-fill RBCs compared with different resin-core materials when light activated immediately after manipulation and after 5minutes delay for developing the chemical cure. The null hypotheses were: 1) The light activation of dual-cure resin-based materials immediately or after 5-minutes would not modify the mechanical properties; 2) the physical and mechanical properties of resin-based materials would be similar when used for restoring endodontic treated teeth.

MATERIAL AND METHODS

Nine dual-cure resin materials used for restoring endodontic treated teeth were tested: 4 resin-core materials: Allcem Core, FGM; Clearfil DC Core Plus, Kuraray; LuxaCore ZDual, DMG; and Rebilda DC, VOCO; 3 automix dual-cure resin cement: RelyX Universal, 3M Oral Care; RelyX U200, 3M Oral Care; and Allcem Dual, FGM; and 2 bulk-fill RBCs: Opus Bulk Fill APS, FGM; and Filtek One Bulk Fill, 3M Oral care. The composition of the materials and manufacturer recommendations are described in Table 1. Two light activation protocols were used for dual-cure resin-based materials: immediately and 5-minutes delayed after manipulation both using a multiwave light curing unit (LCU) VALO Grand; Ultradent. All materials were tested for (Shr, %) using strain-gauge test, filler content (%) using thermogravimetric analysis (TGA), flexural strength (FS) and elastic modulus (E, MPa) using 3-bending test, radiopacity, Knoop hardness (KH, N/mm²), degree of conversion (DC, %), depth of cure (DoC, mm), diametral tensile strength (DTS, MPa) and compressive strength (CS, MPa) all. The resin-based material reminiscent into each mixed tip was weighted. Scanning electric microscopy (SEM) was used to evaluate the morphology of the inorganic filler content.

Post-Gel Shrinkage (Shr)

Post-Gel shrinkage was calculated using the strain-gauge test method with ($n = 5$). The tests were performed in a dark room with orange light and temperature control (22 ± 1 °C). The resin-based material was placed in hemispheres on the top of a biaxial strain gauge (CEA-06-032WT-120, Excel Sensores) that measured shrinkage stresses in both parallel and perpendicular directions. A strain conditioner (ADS05000IP, Lynx) converted electrical resistance variations in the strain gauge into voltage variations and Shr values, through a quarter-bridge with an internal reference resistor ($120 \ \Omega$). The strain values measured along the two axes were calculated since the material properties were considered homogeneous and isotropic on a macro scale. All resin-based materials were light activated according to the two protocols: immediate and delayed, with multi wave LCU (VALO Grand, Ultradent) for 40 s with the LCU tip held at 1.0 mm from the surface of the material. The Shr values were collected for 15 minutes after the light activation. The maximum shrinkage value at the stabilization of the post-gel curves, as used as the post-gel linear shrinkage and converted to a volumetric percentage $\text{Shr} \times 0.0003/100$.

Flexural Strength (FS) and Elastic Modulus (E):

The three-point bending test was used for calculating the flexural strength (MPa) and modulus elasticity (MPa) according to the ISO 4049 (2019).²⁴ Specimens of all resin-based materials ($n = 10$) were prepared using a $2 \text{ mm} \times 2 \text{ mm} \times 25 \text{ mm}$ rubber matrix, in a dark room with orange light. To minimize the presence of bubbles and obtain smooth surfaces, the matrix was placed on a glass plate and a Mylar strip (KDent, Quimidrol) was positioned between the glass plate and matrix. The matrix was filled with mixing tips and, another Mylar strip was placed on the top and the second glass plate was used to force out the excess of the resin cement, the excess was removed, and the material was light activated using two protocols at three points each. After being stored for 24 h in a dry oven at 37 °C, ten specimens from each group were tested. Three-point bending test was carried out using a universal testing machine (Instron ElectroPuls E3000, Instron) at a crosshead speed of 0.5 mm/min and assessed using Bluehill Universal software (Instron Training Center). The surface submitted to the three-point bending test was the top surface that received light directly from the LCU.

The FS was calculated using the following formula: $\alpha = 3FL / (2wt^2)$ where F was the maximum force applied (N), L was the distance between the support beams (mm), w was the width of the specimen (mm), and t was the thickness of the specimen (mm). The modulus of elasticity (MPa) was determined using a deflectometer (W-E401-J, ESeries Deflectometer, Instron) with the tip positioned at the center of the specimen base to measure the deflection during loading. The modulus of elasticity (MPa) was determined using the following formula: $E = FL^3 / 4BH^3 d$ where F was the maximum load (N), L was the length of the specimen (mm), B was the width of the specimen (mm), H was the height of the specimen (mm) and d was the deflection (mm) corresponding to the load F.²⁵

Diametral Tensile Strength (DTS) and Compressive Strength (CS):

DTS and CS (n = 10) were calculated for all resin-based material. The mold for the CS test had 6.0 mm in height and 3.0 mm in diameter; and for the DTS test, the matrix had 2.0 mm in height, and 4.0 mm in diameter. The specimens were light-activated using both protocols, and the specimens were then stored in dark envelopes for 24 h at 37 °C. The specimens were subjected to CS and DTS testing in a universal testing machine (Instron ElectroPuls E3000, Instron) at a crosshead speed of 0.5 mm/min until failure occurred and the load to fracture load (N) was assessed using Bluehill software (Instron). CS values (MPa) were calculated by dividing the F, fracture load (N) by the cross-sectional area (mm²): CS (MPa) = $F/\pi r^2$, where “r” was the radius of the specimen. The DTS (MPa) values were calculated using the following equation: DTS = $2F/\pi dt$, where “F” is the fracture load, “d” was the specimen diameter (mm), and “t” was the height of the specimen (mm).

Knoop Hardness (KH)

Each resin-based material was manipulated and inserted into a bipartite cylindrical matrix with 4 mm in diameter and 10 mm in thickness. The metallic matrix was placed on a glass slide, filled with the resin-based material subsequently covered with another glass slide. The matrix was filled of all tested resin-based materials that were light-activated using two protocols as described, on the top of the matrix. The LCU tip was positioned as close as possible to the polyester strips and stabilized using metallic support.²⁶ The specimens were stored in dark envelopes, dry location at 37 °C for 24 h.

Subsequently, specimens were positioned on the microhardness tester (FM700; FutureTech Corp., Kawasaki). The KH (N/mm²) along the length of the specimens was measured using 50 g for 15 seconds. Three measurements were made in 5 different positions with 2.5 mm (0, 2.5, 5.0, 7.5, and 10 mm in depth, n = 10).

Degree of Conversion (DC)

The degree conversion (DC) was calculated using (n = 10) to calculate the KH. These specimens were polished to obtain a flat surface, using silicon carbide abrasive paper grit size (#1500, 3M) in the polishing machine (Politriz Aropol VV, AROTEC). The DC was measured with a medium infrared FTIR spectrometer (Vertex 70, Bruker Optik GmbH) using their software (OPUS v.7.8, Bruker Optik). The spectra were obtained between internal standard aromatic C=C bonds (1608 cm⁻¹) and aliphatic C=C bonds (1638 cm⁻¹). The baseline of each uncured resin cement was recorded by scanning the 32 times over a range from 400 cm⁻¹ to 4000 cm⁻¹ at the resolution of 4 cm⁻¹. Data were collected at 25 ± 1 °C and 60 ± 5% humidity conditions in a dark room with orange light. Due to the lack of internal reference aromatic peaks at (1608 cm⁻¹) in resin cement RelyX Universal, the (1710 cm⁻¹) peak height was used.²⁷ The formula used to calculate the degree of conversion was $DC (\%) = (1 - C/U) \times 100$.

Depth of Cure (mm)

The same (n = 10) specimens of hardness and degree of conversion were used for the curing depth. They were removed from the matrix and inserted in glass recipient with 100% acetone (NEON, Persoalab). After one hour, the specimens were removed from the glass recipient, and dried for one hour, in the laboratory with temperature control (22 ± 1 °C). The specimens were then photographed with a DSLR camera (D7200, Nikon) coupled to macro lenses (105 mm f/2.8 VR Micro-NIKKOR, Nikon). The specimens were measured with a digital caliper (Mitutoyo, Japan) and the values were divided by 2 to obtain the DoC values following the ISO 4049 recommendations.²⁸

Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA/ SDTA861e) was used to obtain the filler mass fractions (%) of tested materials with (n = 3). TGA measured the change in mass of the resin-based materials as a function of temperature. Approximately 0.005 mg of each

resin-based material, light-activated for 40 s using 2 tested protocols. The specimen was placed in thermogravimetric analyzer (model TGA 55, TA Instruments), immersed placed in standard NETZSCH alumina 85 mL crucibles attached to the thermosanalytical unit (TGA-50, Netzsch-Thermische Analyse) with a TA System Controller (TASC 414/2), a temperature range of 10–900 °C, at a heating rate of 10 °C/minute during approximately 80 minutes, and under synthetic air dynamics (50 mL/min). After being subjected to this test, only the filler remained, and the filler content was calculated considering the % of the mass remained.

Radiopacity

Digital radiographs were taken using the standardized specimens measuring 5 mm in length, 2 mm in width, and 2 mm in thickness. The specimens (n = 10) were positioned over a phosphor plate (size 2, Durr Dental), and radiographic exposure was performed using radiography equipment (Timex 70 E, Gnatus) exposing the specimens to 0.07 seconds to 70 kV and 7.0 mA. The aluminum scale - with thickness from 1 to 10 mm, increasing every 1 mm (Odeme) was placed on the matched plate, with 20 centimeters of focal length. Radiopacity was determined using ImageJ software.^{11,29,30}

Five locations were determined on each specimen, proportional to its length, where the mouse cursor was positioned to collect the radiopacity value. The average of the five calculated values was used as the radiopacity level for each resin-based material. A value is assigned to each pixel to represent a specific shade of gray. These pixel values range from 0 to 255, where 0 represents the darkest gray or black and 255 represents the lightest gray or white.

Scanning Electric Microscopy Analysis (SEM) / Energy Dispersive Spectroscopy (EDS)

The morphology and size of the filler content were evaluated by scanning electric microscopy (SEM) analysis. Specimen 0.3 g of each base and catalyst of resin-based material were inserted on a conical bottom centrifuge tube in polypropylene (Falcon, Vitchlab) in 5 mL of acetone and centrifuged for 2 minutes at 1,000 rpm, this process was repeated 3 times. The remaining material mass was immersed 3 times in 5 mL of chloroform P.A (Alphatec) and centrifuged as described above to further wash and eliminate the matrix.³¹ The filler content was then smeared over the aluminum stubs,

and sputter coated with gold/palladium in a high vacuum (QR 150ES, Quorum). The specimens were examined with a scanning electron microscope (VEGA 3 LMU, Tescan) operating at 20.00 Kv. Images were obtained at 5,000, 10,000, and 20,000 × magnification. Particle composition was determined using the powder obtained, observed in an SEM / EDS integrated analysis system (INCA X-ACT model 51ADD0007, Oxford). Analyses were performed at a working distance of 14.9 mm, 20 Kv, variable spot size to obtain a lifetime of 30 seconds, and dead time of 20 %. For each specimen, one scan analysis of 4 s was performed, using a magnification of 5000 x.

Weighting of mixing tips (g)

The mixing tips used for mixing the materials used for previous tests were weighted using an analytical balance (AG200, Gehaka Ltda) before using and after mixing and inserting the resin-based materials ($n = 20$). The weight of residue was calculated by the subtraction of the final by initial weight (g).

Statistical Analysis

Data were tested for normal distribution (Shapiro-Wilk) and equality of variances (Levene test), followed by parametric statistical tests. Data from Shr, TGA, FS, E, DTS, CS, DoC, and radiopacity, were analyzed using 2-way ANOVA and KH and DC were analyzed using 2-way repeated measures ANOVA, followed by Tukey. All statistical analyses were performed using Sigma Plot 12.0 (Stata Corp, College Station, TX) and all tests were performed using a level of significance of $\alpha = 0.05$.

Results Shr (%)

The mean and standard deviation values of resin-based materials light-activated using both protocols are reported in Figure 1. Two ANOVA showed that there was significant difference between the resin-based materials ($p < .001$), and between light activation protocols ($p < .001$). Tukey's test showed that the delayed light activation reduced significantly the Shr for all resin-core and dual-cure resin cements. No difference was found between Shr values of both tested bulk-fill RBCs. In general, the resin-core materials when light-activated immediately had similar or higher Shr values than bulk-fill RBCs; however, when light-activated after 5-minutes all the materials tested had

lower Shr values than bulk-fill RBCs. The dual-cure resin cements in general had lower Shr than resin-core materials when both were light-activated immediately, however this difference tend to disappear with delayed light activation protocol.

Flexural Strength (FS, MPa)

The FS mean and standard deviation values of all resin-based materials are shown in Figure 2. Two-way ANOVA showed significant difference between resin-based materials ($p < .001$), but no significant difference of light activation protocols ($p = .302$). Rebilda DC had the highest FS value, followed by both tested bulk fill resin composite, Clearfil DC Core Plus and Allcem Core, and RelyX Universal, RelyX U200 and LuxaCore Z had the lowest FS values ($p < .001$).

Elastic Modulus (E, MPa)

The E mean and standard deviation values of all resin-based materials are shown in Figure 3. Two-way ANOVA showed significant difference between resin-based materials ($p < .001$), but no significant difference of light activation protocols ($p = .101$). OPUS Bulk Fill APS had the highest E value, followed by Clearfil DC Core Plus, and RelyX Universal had the lowest E values ($p < .001$).

Diametral tensile strength (MPa)

The DTS mean values and standard deviations of all resin-based materials using different light activation protocols are reported in Figure 4. Two-way ANOVA showed there was a significant difference between the resin-based materials ($p < .001$), the light activation protocol ($p < .001$), and also for the interaction between both study factors ($p < .001$). Tukey's test showed that for the bulk-fill RBCs and Clearfil DC Core Plus had the highest and RelyX Universal and RelyX U200 had the lowest DTS values. The delayed light activation protocol had a significative influence on the DTS values only for Clearfil DC Core Plus.

Compressive strength (MPa)

The CS mean values and standard deviations of all resin-based materials using different light activation protocols are reported in Figure 5. Two-way ANOVA showed there was a significant difference between the resin-based materials ($p < .001$), the light activation protocol ($p < .001$), and also for the interaction between both study factors ($p < .001$). Tukey's test showed that for the bulk-fill RBCs, Rebilda DC and Clearfil DC Core Plus when light-activated after 5-minutes had highest and RelyX Universal had the lowest CS values. The delayed light activation protocol had significative influence on the CS values only for Clearfil DC Core Plus.

Knoop Hardness (KH, N/mm²)

The KH mean values and standard deviations of all resin-based materials using different light activation protocols are reported in Figure 6. There was a high correlation between depth increasing and the reduction in the KH values for all materials ($p < .001$). Twoway ANOVA showed there was a significant difference between the resin-based materials ($p < .001$), the light activation protocol ($p < .001$), and also for the interaction between both study factors ($p < .001$). Tukey's test showed that the bulk-fill RBCs and resin-core materials had in general higher KH values than dual-cure resin cements. The KH values always significantly higher at the top than at the 5 mm depth or deeper measurement. The delayed light activation protocol increased the KH values in deep locations for RelyX Universal and LuxaCore Z; and for Allcem Core and RelyX U200 at 0 to 5 mm. No influence of light activation protocol was observed for Clearfil DC Core Plus and Allcem Dual.

Degree of Conversion (%)

The DC mean values and standard deviations of all resin-based materials using different light activation protocols are reported in Figure 7. There was a high correlation between depth increasing and the reduction on the DC values for all materials ($p < .001$). Twoway ANOVA showed there was a significant difference between the resin-based materials ($p < .001$), and also for the interaction between both study factors ($p < .001$). Tukey's test showed that for the bulk-fill RBCs and resin-core materials had in general higher DC values than dual-cure resin cements. The DC values always significantly higher at the top than at the 10 mm depth, mainly for bulk-fill RBCs. The delayed light

activation had no significant influence on the DC values, irrespective of resin-based tested material. The reduction of the DC with the increasing of depth was significantly more evident for bulk-fill RBCs than dual-cure resin materials.

Depth of Cure (mm)

The DoC mean values and standard deviations of all resin-based materials using different light activation protocols are reported in Figure 8. There was a high correlation between depth increasing and the reduction on the DoC values for all materials ($p < .001$). Two-way ANOVA showed there was a significant difference between the resin-based materials ($p < .001$) but had no significant difference for light activation protocol ($p = .477$). Tukey's test showed that for the bulk-fill RBCs had significantly lower depth cure of dual cure resin-based materials. The delay of 5-minutes for light activation had no influence on the DoC values.

TGA, Filler content (%)

The filler content in weight (%) mean and standard deviation values of resin-based materials light-activated using both protocols are reported in Figure 9. Two ANOVA showed significant difference between the resin-based materials ($p < .001$), but no significant difference for light activation protocols ($p = .411$). Tukey's test showed that the bulk-fill RBCs and the most of resin-core materials had higher filler content than dual-cure resin cements. Both tested bulk-fill RBCs, Clearfil DC Core Plus and Rebilda DC had the highest filler content and RelyX Universal had the lowest filler content in weight ($p < .001$).

Radiopacity

The mean and standard deviation radiopacity values of all resin-based materials using both light activation protocols are shown in Figure 10. Two-way ANOVA showed significant difference between the resin-based materials ($p < .001$); however, no difference was found between the activation protocol ($p = .311$). Tukey's test showed all tested resin-based materials demonstrated radiopacity level that was equivalent to, or higher, than the 4 mm aluminum step-wedge. The light activation protocol had no influence on the radiopacity.

SEM analysis / EDS

The morphology of the filler content of the composites evaluated in this study at 5,000 x, 10,000 and 20,000 are shown in Figure 12. The materials evaluated presented in general irregular particles with different sizes and agglomerated, except for Allcem Core that presented more homogenous fillers without agglomerate, and RelyX Universal which presented only nanoparticles in the catalyst. The Clearfil DC Core Plus, RelyX U200, and LuxaCore Z had the largest particle size.

The EDS analysis showed the prevalent components of the filler content of all resin-based materials tested were found oxygen and silica, followed by carbon, barium, and aluminum. except for RelyX Universal which also presented ytterbium, fluorine, strontium, and bromine; RelyX U200 had fluorine, strontium, lanthanum, sodium, phosphorus, and calcium; and Filtek One Bulk Fill had zirconium and ytterbium, shown in Figure 13.

Material residue in mixing tip (Weight – g, %)

The weight of residue material inside the mixing tip mean values and standard deviations are reported in Figure 11. One-way ANOVA showed there was a significant difference between the resin-based materials ($p < .001$). A different percentage of lost cement was observed with Allcem Dual (5.8%) and Allcem Core (4.1%), RelyX U200 had (3.0%), showing Clearfil DC Core Plus (3.2%) more residue compared to LuxaCore Z (2.9%) and Rebilda DC (2.9%). Conversely, RelyX Universal (2.2%) was found to have the least consumption. Tukey's test showed that for the RelyX Universal had significantly lower and RelyX U200 had the highest residue inside the mixing tips. Among resin-core materials Allcem Core and LuxaCore Z had significantly residue inside the mixing tip than Clearfil DC Core Plus and Rebilda DC.

Discussion

This study evaluated if the material type and the light activation protocol can influence the physical and mechanical properties of the resin-based materials used for restoring endodontically treated teeth. The delayed light activation of the dual-cure resin-based materials reduced the Sh_r and produced similar or higher physic-mechanical properties, then the first null hypothesis was rejected. The dual-cure resin-based materials tend to stabilize in mass with time and does not suffer immediately the change the monomers to

polymers in one single moment, reducing shrinkage stresses.²¹ Dual-cure resin cements are characterized by two forms of initiating the polymerization: first, polymerization of dimethacrylate initiated by free radicals, and second by light activation, in this sense the self-curing mode compensates for the lack of light incidence in opaque areas of the restoration.¹⁷ During the initial polymerization, the stiffness of the material is gained and the capacity to deform is reduced.²⁵ The immediate light activation tend to accelerate the cure process, reducing the capacity of the dissipate the stress generated during light activation. The E is related to the stress transmission between the final restoration and the reminescent tooth structure, indicating the ability of the resin-based materials to resist the elastic deformation that can damage the integrity of the bonded interface.⁶ Resin-based materials that have high elastic modulus produce more rigid restorations, therefore the modulus of elasticity is intimately linked to the hardness.⁷ The E of the resin-based materials should have a nearly intermediary elastic modulus of the dentin that is going to be replaced 18.6 (MPa).²⁵ In this study the E values tend to correlate with the filler content, confirming that bulk-fill RBCs and resin-core materials presented higher filler content and also higher E values, in contrast to RelyX Universal which had lower E values. An increase in filler content generally leads to higher observed E values.⁷

The FS is an important mechanical property of brittle materials. ISO 4049 prescribes a minimum FS of 50 MPa for luting materials to support masticatory loading.²⁴ All tested materials achieved the FS parameter recommended, justifying the similarity between materials used for both strategies for restoring endodontic treated teeth. DTS and CS are also important mechanical properties, because resin-core materials usually replace large quantity of tooth structure and should provide sufficient strength to resist compressive forces and intraoral tensile stress.²⁰ The influence of these materials in the daily practice of clinicians is important because many clinical failures are due to tensile stress in the process of mastication which has two or more sets of forces applied in opposite directions.¹⁰

High percentages of filler can affect the post-gel shrinkage subsequently increasing the fracture strength.⁴ This aspect can explain higher Shr values for bulk-fill RBCs and resin-core materials with higher filler content compared with dual-cure resin cements. Delayed light activation of 5-minutes also increases the Ph-buffering which is important to permit adequate polymerization.¹⁸

In some studies, the delay light activation demonstrated also improving on the mechanical properties such as Knoop hardness, elastic modulus, and bond strength of the dual-cure resin cement, and reduce the residual shrinkage stress.¹⁹⁻²² The material possesses a higher gel phase which dissipates the shrinkage volume stress, therefore when photo-activated immediately there is a shock of particles that shrink quickly to the medium. In the gel phase is yielded softer to posteriorly harden and this abrupt change improves fast vitrification of the resin-based materials.^{11,25} However, this mechanism did not improve consistently the physic-mechanical properties tested in this study.

The mechanical properties of resin-core materials, dual-cure resin cement, and bulk-fill RBCs were material-dependent, then the second null hypothesis was also rejected. The physical, mechanical, and biological properties of resin-based materials are strongly influenced by the DC achieved by the organic matrix.²⁷ Whereas the DC, DoC, and KH did not differ between immediate and delayed light activation protocols. The 5-minutes delay light activation resulted only in increasing KH. Development of the DC continues for some time even after the restoration is completed.^{28,29} The high DC values can also be related to the polymer formation with not well stable or strongly connected network, which can explain the more evident reduction for KH values in deep locations. KH represents the deformation of the resin-based material when suffer load to be penetrated. The KH values can be compared to the dentin hardness, having to overcome cracking in brittle materials.^{27,4} The KH values reduced when depth increased. The light attenuation reduces the energy delivered on the deep areas, making the only chemical reaction not sufficient to achieve the same polymerization quality through the material depth. This finding highlights the necessity of using of LCU with high power and well distributed light on the LCU tip.^{9,26} The resin-core materials had higher KH than bulkfill RBCs at deeper locations due their chemical initiators mediated by the peroxideamine binary redox system.²⁷ The higher DC values observed for dual-cure resin cement resulted in higher KH values.⁵ However, the bulk fill RBCs depends on the light reach the deep higher than 4 to 5 mm, confirming that the concept that bulk-fill restoration not always allows single increment.

Higher DC values have been associated with improved mechanical properties of resin-based materials.²⁷ In cases where there is no proper light-curing, like at gingival floor, the DC depends on the chemical conversion of the monomers to polymers.⁴ must be preserved at the bottom of the restoration because it is useless to have a material that

loses all its properties at deep regions, being a barrier and sealing material guaranteeing the success of the canal treatment in the long term.⁸ In the case of core build-up, the resin-based material may not be polymerized properly, being susceptible for cracking when the patient leaves with the temporary restoration or even when the definitive restoration is luted.²⁸ Resin-based materials that do not achieve the suitable DC, have been associated with problems such as microleakage, wear resistance, recurrent caries, discoloration, susceptibility to degradation and finally decrease in mechanical properties.¹⁰ In this study, the DC values were higher for dual-cure resin cements than bulk-fill RBCs at deep locations, that can explain the lower DoC, KH at 7.5 and 10 mm depth. However, we need to consider that bulk-fill RBCs is not recommended to be used for 10 mm, all tested bulk-fill RBCs achieved the recommended depth polymerization of 5 mm, as described by manufactures.

Differences between materials regarding the filler content, monomer integration, and filler size can be directly related to the mechanical properties.¹⁹ This filler mass % may influence resin-based material's E, KH, and FS.¹⁴ High inorganic contents have been associated with more homogenous E and KH values distribution that produces strength restorations in depth.⁴ The UDMA network give lower viscosity facilitates the migration of free radicals, therefore increasing the crosslinking, which subsequently increases FS values.¹⁷ This study showed heterogeneity of mechanical properties that occur in clinical scenarios where indirect restorations have complex luting because light activation is considerably attenuated or barred in areas of difficult site.²³ The resin-based materials present different radiopacities to improve radiographic monitoring.^{11,29,30} Adequate radiopacity allows better diagnosis and differentiation of marginal gaps, secondary caries, marginal overhangs extending to subgingival regions, and delineate tissues and structures such as enamel, dentin, and other reconstruction portions such as fiberglass posts, metal post, and crowns.²⁴ The presence chemical elements such as Zirconium, Strontium, Lanthanum, Magnesium, Ytterbium, Barium, Zinc and Yttrium increase the radiopacity properties.¹² Barium was the most used radiopaque material, except for 3M Oral Care materials that had Ytterbium, Strontium and Lanthanum. The tested bulk-fill RBCs contain higher atomic number Barium ($Z = 56$), that gave higher radiopacity, followed by Filtek One Bulk Fill, with atomic numbers; Zirconium ($Z = 40$), Yttrium ($Z = 39$). Therefore, the content of radiopaque additives in the inorganic filler influences the radiopacity test.

As expected, some resin-based materials remained inside the mixing tips. However, this study demonstrated that the different automixed materials presented significant differences in the residues inside the tip after mixing the material. Considering the volume and weight of the total material presented in one syringe, different percentages observing the lost cement in the percentage of Allcem Core (4.1%) and LuxaCore Z (2.9%) presented more residue inside than Clearfil DC Core Plus (3.2 %) and Rebilda DC (2.9%). Allcem Dual (5.8%) and RelyX U200 (3.0%) RelyX Universal had (2.2%). The waste of material has significant implications, as it not only increases costs associated with the purchase of tips to achieve optimal clinical outcomes but also results in material loss. This dilemma often compels clinicians to make choices regarding the use of resin cement based on factors such as lower cost, larger quantities of material, more tips, and greater market accessibility.

This study had some limitations, although all the experimental tests were conducted under favorable conditions. They did not replicate the real clinical challenges posed by various oral conditions such as mouth opening, tooth positioning within the oral cavity, and the need to reach deeper locations with light curing tip when working with resin-based materials.

It is important to emphasize that mechanical properties are affected by the material type and composition.⁴ The resin-core materials showed satisfactory results, similar in most cases or superior to dual-cure resin cements used to cement the fiberglass post and to the RBC that is used to build the core structure. This performance can be explained by the similar higher filler content observed for all resin-core materials, when compared with bulk-fill RBCs. Also, the adequate polymerization in deeper locations observed in this study can support the capacity for fiberglass posts in root canals. The comprehensive analyses of the physical and mechanical properties of the resin-core materials can support that the rehabilitation of the endodontically treated tooth with the cementation of the post, core build-up, and definitive cementation of the prosthesis can be achieved with these in a single phase and with the same material.^{5,21}

The use of resin-core materials can save working time, improving the efficiency and effectiveness of the restorations by avoiding multiple material interfaces. This study showed that, based on the physical and mechanical properties, the option for using the resin-core dual cured materials to cement the fiberglass post, rebuild the core, and cement the final prosthesis is an option for restoring endodontic treated teeth. Moreover,

the findings of this study further validate the clinical recommendation proposed in previous studies,¹⁹⁻²² which suggests that the strategy for dual-cure resin cements can be extrapolated to resin-core materials.

Conclusions

Within the limitations of the study design the following conclusions can be drawn:

1. The delayed activation protocol waiting 5-minutes after mixing dual cure resinbased materials significantly reduced the post-gel Shr without affecting or improving all the tested mechanical properties.
2. Dual cure resin-core materials presented similar mechanical properties to bulk-fill RBCs, allowing to perform core build-up with a single material.
3. Dual-cure core materials presented a higher depth of cure than bulk-fill RBCs, and similar or higher mechanical properties to dual-cure resin cements used for luting fiberglass post and final indirect restorations.
4. The resin-based materials remained into the mixing tip varied significantly ranging between 5.8% to 2.2% in weighted for all tested materials.
5. The radiopacity of all materials was higher than the recommendation of ISO 4049.

REFERENCES

1. Bergoli CD, Brondani LP, Wandscher VF, Pereira G, Cenci MS, Pereira-Cenci T, Valandro LF. A Multicenter Randomized Double-blind Controlled Clinical Trial of Fiber Post Cementation Strategies. *Oper Dent* 2018;43:128-35.
2. de Kuijper MCFM, Cune MS, Özcan M, Gresnigt MMM. Clinical performance of direct composite resin versus indirect restorations on endodontically treated posterior teeth: A systematic review and meta-analysis. *J Prosthet Dent* 2021;31:S0022-3913:00634-X.
3. Bitter K, Schubert A, Neumann K, Blunck U, Sterzenbach G, Rüttermann S. Are self-adhesive resin cements suitable as core build-up materials? Analyses of maximum load capability, margin integrity, and physical properties. *Clin Oral Investig* 2016;20:1337-45.
4. Koytchev E, Yamaguchi S, Shin-No Y, Suzaki N, Okamoto M, Imazato S, Datcheva M, Hayashi M. Comprehensive micro-mechanical characterization of experimental direct core build-up resin composites with different amounts of filler contents. *Dent Mater J* 2019;38:743-9.
5. Lien W, Roberts H, Vandewalle K. Hardness development in resin composite core materials. *J Prosthodont* 2022;31:305-13.
6. Zenthöfer A, Rues S, Rammelsberg P, Ohlmann B, Bömicke W. Influence of geometric dimensions on early failures of adhesively retained composite resin core build-ups. *J Esthet Restor Dent* 2023;35:435-41.
7. Soares CJ, Bicalho AA, Tantbirojn D, Versluis A. Polymerization shrinkage stresses in a premolar restored with different composite resins and different incremental techniques. *J Adhes Dent* 2013;15:341-50.
8. Pereira RD, Valdívila AD, Bicalho AA, Franco SD, Tantbirojn D, Versluis A, Soares CJ. Effect of photoactivation timing on the mechanical properties of resin cements and bond strength of fiberglass post to root dentin. *Oper Dent* 2015;40:E206-21.
9. Bragança GF, Vianna AS, Neves FD, Price RB, Soares CJ. Effect of exposure time and moving the curing light on the degree of conversion and Knoop microhardness of light-cured resin cements. *Dent Mater* 2020;36:e340-51.
10. Warangkulkasemkit S, Pumpaluk P. Comparison of physical properties of three commercial composite core build-up materials. *Dent Mater J* 2019;38:177-81.

11. Soares CJ, Rosatto C, Carvalho VF, Bicalho AA, Henriques J, Faria-E-Silva AL. Radiopacity and porosity of bulk-fill and conventional composite posterior restorations-digital x-ray analysis. *Oper Dent* 2017;42:616-25.
12. Erzurumlu ZU, Sagirkaya CE, Erzurumlu K. Evaluation of radiopacities of CAD/CAM restorative materials and resin cements by digital radiography. *Clin Oral Investig* 2021;25:5735-4.
13. Oliveira L, Melo C, Cavalcanti K, Soares P, Cardenas A, Soares CJ. Effects of Adjacent Tooth Type and Occlusal Fatigue on Proximal Contact Force of Posterior Bulk Fill and Incremental Resin Composite Restoration. *Oper Dent* 2022;47:64-75.
14. Spinhayer L, Bui ATB, Leprince JG, Hardy CMF. Core build-up resin composites: an in-vitro comparative study. *Biomater Investig Dent* 2020;7:159-66.
15. Mazão JD, Braga S, Brangança G, Zancopé K, Price RB, Soares CJ. Effect of ceramic thickness on light attenuation, degree of conversion, knoop hardness, and elastic modulus of four luting resins. *Oper Dent* 2023;48:226-35
16. Novais VR, Raposo LH, Miranda RR, Lopes CC, Simamoto PC Júnior, Soares CJ. Degree of conversion and bond strength of resin-cements to feldspathic ceramic using different curing modes. *J Appl Oral Sci* 2017;25:61-8.
17. El-Damanhoury HM, Elsahn NA, Sheela S, Albasti AA, Jouma MJ, Albadich MA, Bastaty T, Taghva YS. Impact of immediate and delayed photo-activation of selfadhesive resin cements on bonding efficacy and water uptake under simulated pulpal pressure. *Oper Dent* 2022;47:337-45.
18. Faria-e-Silva AL, Peixoto AC, Borges MG, Menezes Mde S, Moraes RR. Immediate and delayed photoactivation of self-adhesive resin cements and retention of glass-fiber posts. *Braz Oral Res.* 2014;28.
19. Soares CJ, Bicalho AA, Verissimo C, Soares P, Tantbirojn D, Versluis A. Delayed photo-activation effects on mechanical properties of dual cured resin cements and finite element analysis of shrinkage stresses in teeth restored with ceramic inlays. *Oper Dent* 2016;41:491-500.
20. Faria-E-Silva AL, Pfeifer CS. Delayed photo-activation and addition of thiourethane: Impact on polymerization kinetics and stress of dual-cured resin cements. *J Dent* 2017;65:101-9.

21. Taylor R, Fuentealba R, Brackett WW, Roberts HW. 24 hour polymerization shrinkage of resin composite core materials. *J Esthet Restor Dent* 2021;33:775-85.
22. Mazzitelli C, Maravic T, Mancuso E, Josic U, Generali L, Comba A, Mazzoni A, Breschi L. Influence of the activation mode on long-term bond strength and endogenous enzymatic activity of dual-cure resin cements. *Clin Oral Investig* 2022;26:1683-94.
23. Liu W, Rudmann M, Yune S, Adcock R, Watson N, Hamlin N. Effect of ultrasonic vibration on the presence of voids in core build-up materials. *Gen Dent* 2023;71:31-6.
24. International Organization for Standardization. ISO 4049 (2019). Dentistry Polymer-based filling, restorative materials. International Standards Office, Geneva, Switzerland.
25. Hordones Ribeiro MT, Felipe de Bragança G, Sales Oliveira LR, Lourenço Braga SS, Quirino de Oliveira HL, Price RB, Soares CJ. Effect of pre-heating methods and devices on the mechanical properties, post-gel shrinkage, and shrinkage stress of bulk-fill materials. *J Mech Behav Biomed Mater* 2023;138:105605.
26. Soares CJ, Braga S, Price RB. Relationship between the cost of 12 light-curing units and their radiant power, emission spectrum, radiant exitance, and beam profile. *Oper Dent* 2021;46:283-92.
27. Aldhafyan M, Silikas N, Watts DC. Influence of curing modes on conversion and shrinkage of dual-cure resin-cements. *Dent Mater* 2022;38:194-203.
28. Price RB, Rueggeberg FA, Harlow J, Sullivan B. Effect of mold type, diameter, and uncured composite removal method on depth of cure. *Clin Oral Investig* 2016;20:1699-707.
29. Fonseca RB, Branco CA, Quagliatto PS, Gonçalves Lde S, Soares CJ, Carlo HL, Correr-Sobrinho L. Influence of powder/liquid ratio on the radiodensity and diametral tensile strength of glass ionomer cements. *J Appl Oral Sci* 2010;18:577-84.
30. Hosney S, Abouelseoud HK, El-Mowafy O. Radiopacity of Resin Cements Using Digital Radiography. *J Esthet Restor Dent* 2017;29:215-21.
31. Carlo HL, Fonseca RB, Soares CJ, Correr AB, Correr-Sobrinho L, Sinhoreti MA. Inorganic particle analysis of dental impression elastomers. *Braz Dent J* 2010;21:520-7.

Table

Table 1. Resin cements and bulk fill resin composite tested

Materials	Type	Manufacturers	Primary Components	Weight	Volume	Lot Number	Shade
Clearfil DC Core Plus	Core Build-up Resin Cement	Kuraray	Inorganic fillers range from 0.01 μm to 20 μm . Paste A: Bis-GMA, Hydrophobic aliphatic dimethacrylate, Hydrophilic aliphatic dimethacrylate, Hydrophobic aromatic dimethacrylate, Silanated barium glass filler, Silanated colloidal silica, Colloidal silica, dl-Camphorquinone, Initiators and Pigments. Paste B: TEGDMA, Hydrophilic aliphatic dimethacrylate, Hydrophobic aromatic dimethacrylate, Silanated barium glass filler, Silanated colloidal silica, Aluminum oxide filler and Accelerators.	Not specified	52%	5MO392	Dentin
LuxaCore Z-Dual	Core Build-up Resin Cement	DMG	Mean of filler size is about 0.02 - 2.4 μm . Barium glass, pyrogenic silicic acid, nanofiller and zirconium dioxide in a Bis-GMA based matrix from dental resin.	70%	50%	241962	A3
Rebilda DC	Core Build-up Resin Cement	VOCO	Bis-GMA, UDMA, BHT and benzoyl peroxide.	Not specified	Not specified	2131566 , 2143447 and 2032447	Dentine
Allcem Core	Core Build-up Resin Cement	FGM	Base paste: metacrylate monomers such as BisGMA, Bis EMA and TEGDMA, camphoroquinone, coinitiators, barium-aluminium-silicate glass microparticles and nano-particles of silicon dioxide, inorganic pigments and conservers. Catalyst paste: methacrylic monomers, dibenzoyl peroxide, stabilizers and Barium -Aluminium-silicate glass micro-particles.	62%	Not specified	150920, 170322, 010421 and 130922.	A2
RelyX Universal	Dual Cure Resin Cement	3M Oral Care	Catalyst Paste: YbF3, UDMA, Silane treated glass powder, TEGDMA, Silane treated silica, Initiator, pigments, e.g., Titanium dioxide, HEMA. Base Paste: TEGDMA, Silane treated silica, UDMA, Hydroperoxide.	Not specified	Not specified	8402901 and 8452689	AO3
RelyX U200	Dual Cure Resin Cement	3M Oral Care	Mean of filler size is about 12.5 μm . Base past: methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, ionitiator components, stabilizers and reheological additives. Catalyst paste:	70%	Not specified	8299171 and 8629419	A2

Allcem Dual	Dual Cure Resin Cement	FGM	methacrylate monomers alkaline (basic) fillers, silanated fillers, initiator components, stabilizers, pigments and rheological additives. Base paste: metacrylate monomers such as BisGMA, Bis EMA and TEGDMA, camphoroquinone, coinitiators, barium-aluminium-silicate glass microparticles, particles of silicon dioxide, inorganic pigments and preservatives. Catalyst paste: methacrylate monomers, dibenzoyl peroxide and stabilizers aluminium-silicate glass microparticles.	66-67%	Not specified	300622, 1710022 and 130122	A2
Filtek One Bulk Fill	Bulk Fill Resin Composite	3M Oral Care	Non-agglomerated/non-aggregated 20nm silica filler, a non-agglomerated/non-aggregated 4 to 11nm zirconia filler, an aggregated zirconia/silica cluster filler (comprised of 20nm silica and 4 to 11nm zirconia particles) and a YbF3 filler consisting of agglomerate 100nm particles. Contains AFM (dynamic stress-relieving monomer), AUDMA,UDMA and DDDMA.	76.5%	58.5%	NE8832 2 and NF4362 4	A3
Opus Bulk Fill APS	Bulk Fill Resin Composite	FGM	Active ingredients: urethane-dimethacrylic monomers, stabilizers, photoinitiating composition (APS) and co-initiators. Inactive ingredients: inorganic load of silanized silicon dioxide (silica), stabilizers and pigments.	79%	Not specified	190122	A3

Bis-GMA, bisphenol A-glycidyl methacrylate; TEGDMA, Triethyleneglycol dimethacrylate; UDMA, Urethane dimethacrylate; HEMA, 2-hydroxyethyl methacrylate; BHT, butylated hydroxytoluene; YbF3, ytterbium trifluoride; APS, Advanced Polymerization System; AUDMA Aromatic urethane dimethacrylate; AFM, addition fragmentation monomers; DDDMA, 1, 12-Dodecanediol dimethacrylate.

Figures

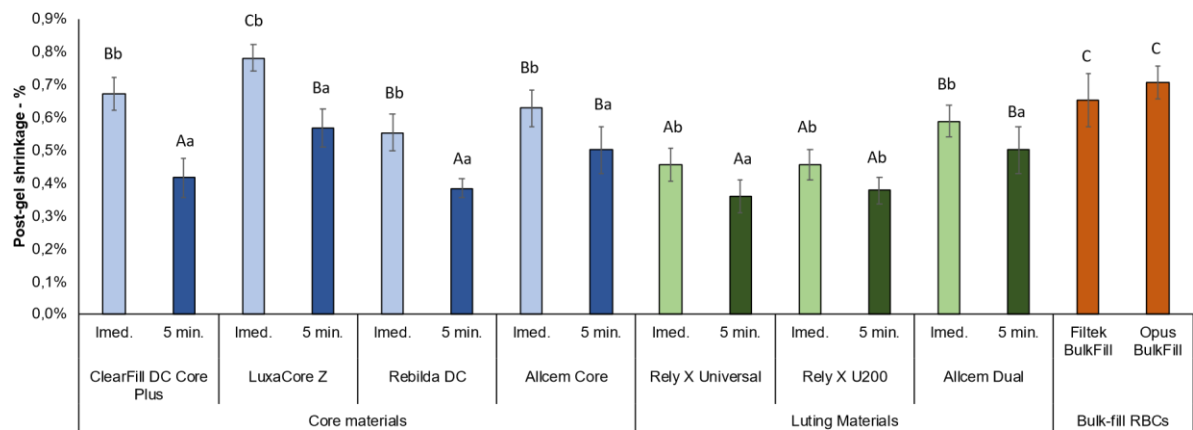


Figure 1. Means and standard deviation values of Shr values (%) for resin-core materials, dual cure resin cements and bulk-fill RBCs. Different letters mean significant difference; upper caser letter used for comparison between materials for each lightactivation protocol; and lower caser letter used for comparison between light activation protocol for each resin-based material.

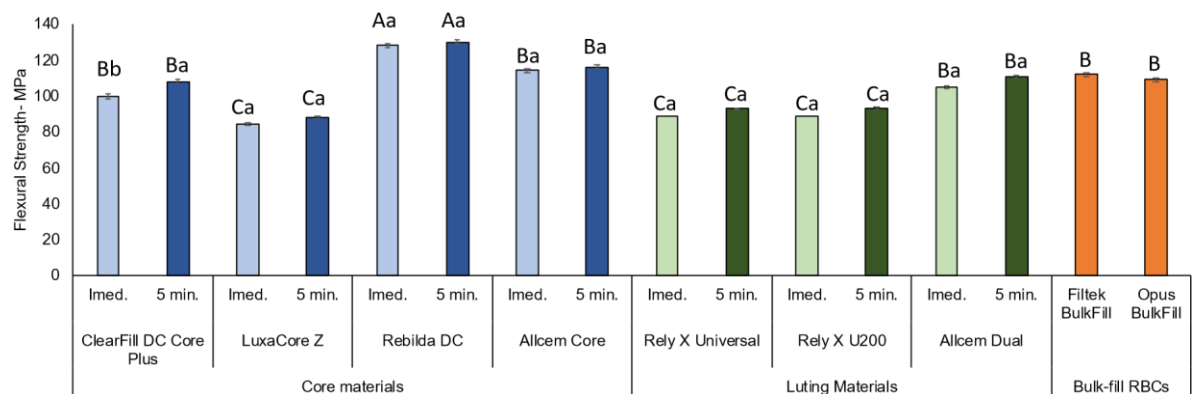


Figure 2. Means and standard deviation of FS values (MPa) for resin-core materials, dual cure resin cements and bulk-fill RBCs. Different letters mean significant difference; upper caser letter used for comparison between materials for each light activation protocol; and lower caser letter used for comparison between light activation protocol for each resin-based material.

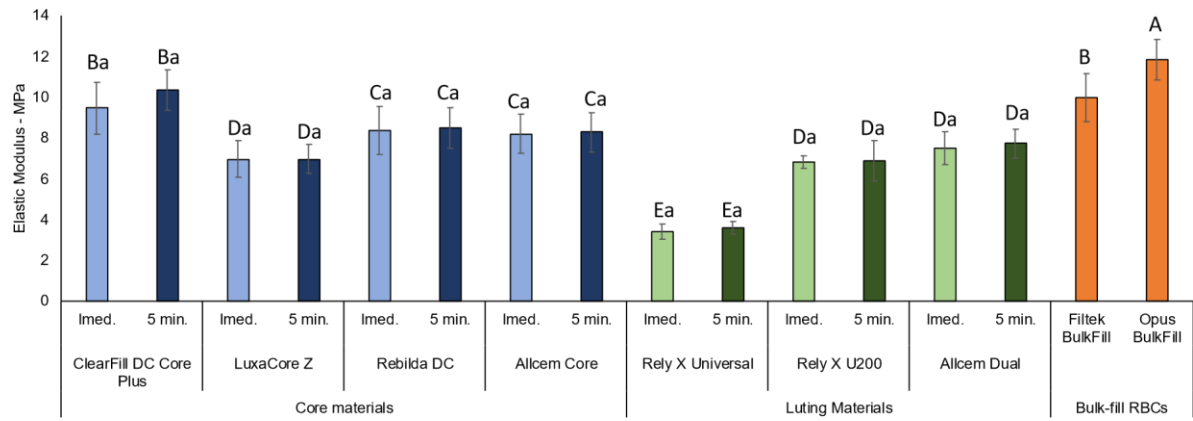


Figure 3. Means and standard deviation of E values (MPa) for resin-core materials, dual cure resin cements and bulk-fill RBCs. Different letters mean significant difference; upper caser letter used for comparison between materials for each light activation protocol; and lower caser letter used for comparison between light activation protocol for each resin-based material.

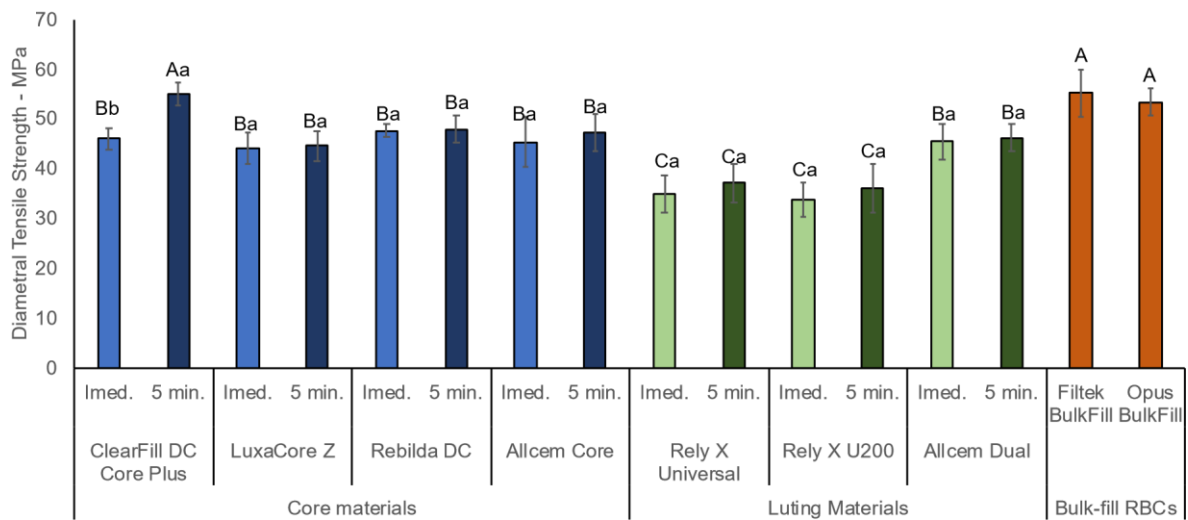


Figure 4. Means and standard deviation of diametral tensile strength values (MPa) for resin-core materials, dual-cure resin cements and bulk-fill RBCs. Different letters mean significant difference; upper caser letter used for comparison between materials for each light activation protocol; and lower caser letter used for comparison between light activation protocol for each resin-based material.

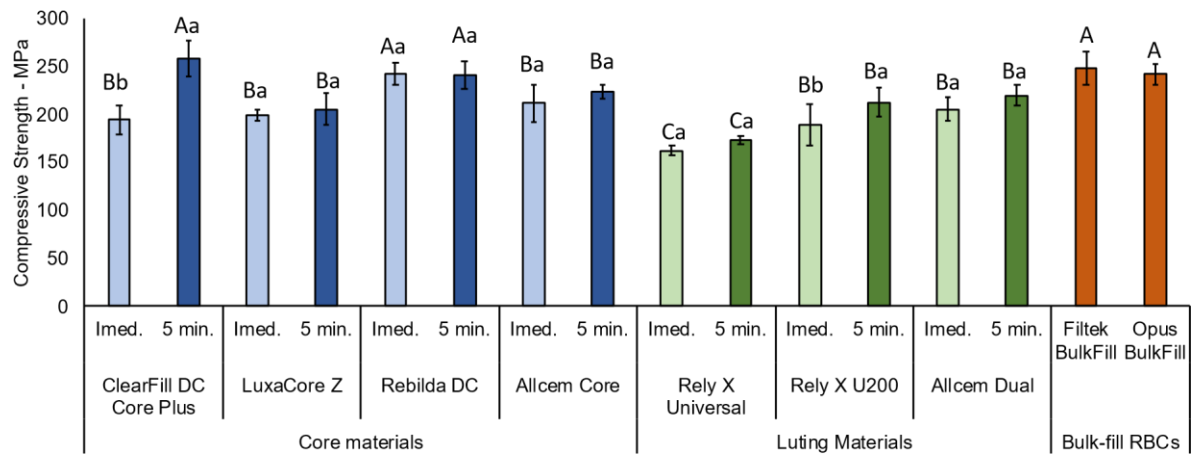


Figure 5. Means and standard deviation of compressive strength values (MPa) for resin-core materials, dual-cure resin cements and bulk-fill RBCs. Different letters mean significant difference; upper caser letter used for comparison between materials for each light activation protocol; and lower caser letter used for comparison between light activation protocol for each resin-based material.

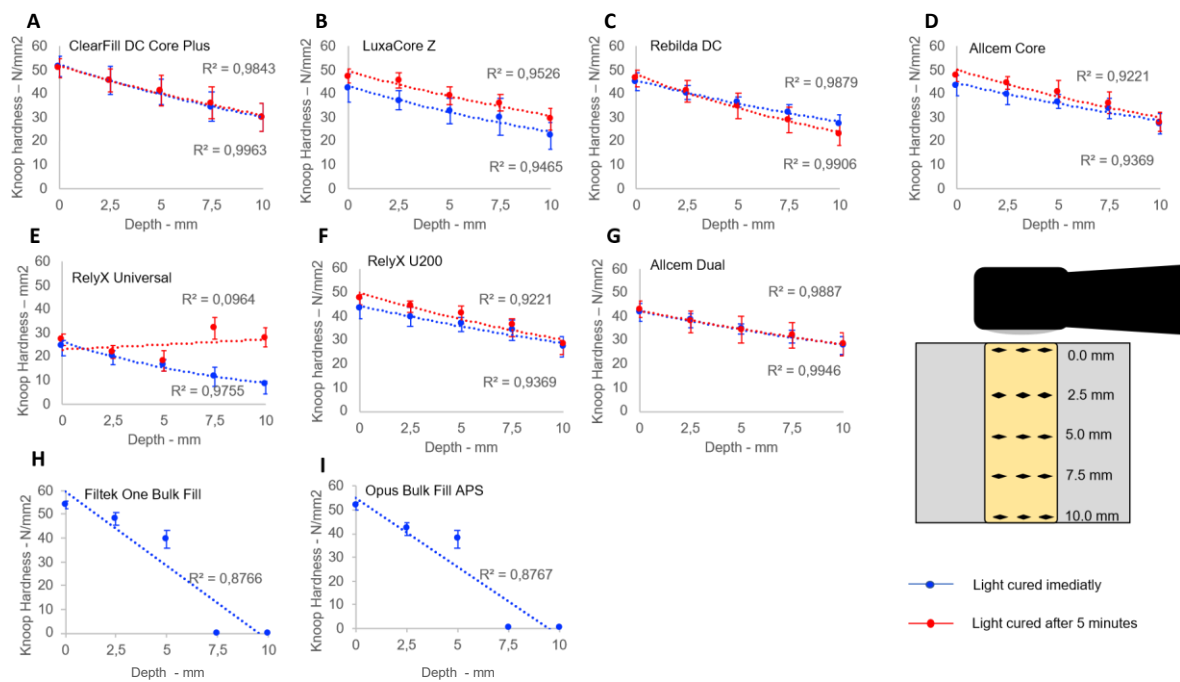


Figure 6. Means and standard deviation of KH values (N/mm²) for resin-core materials, dual-cure resin cements and bulk-fill RBCs. Linear regression of KH values according to the depth of the measurement. Logarithmic regression coefficient (R²) for all resin-based materials.

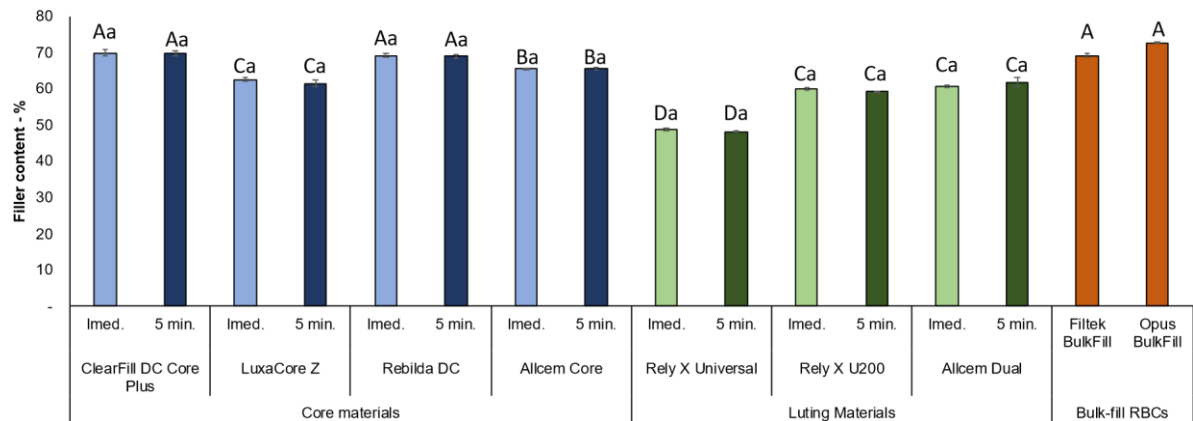


Figure 9. Means and standard deviation of filler content in weight values (%) for resin-core materials, dual-cure resin cements and bulk-fill RBCs. Different letters mean significant difference; upper case letter used for comparison between materials for each light activation protocol; and lower case letter used for comparison between light activation protocol for each resin-based material.

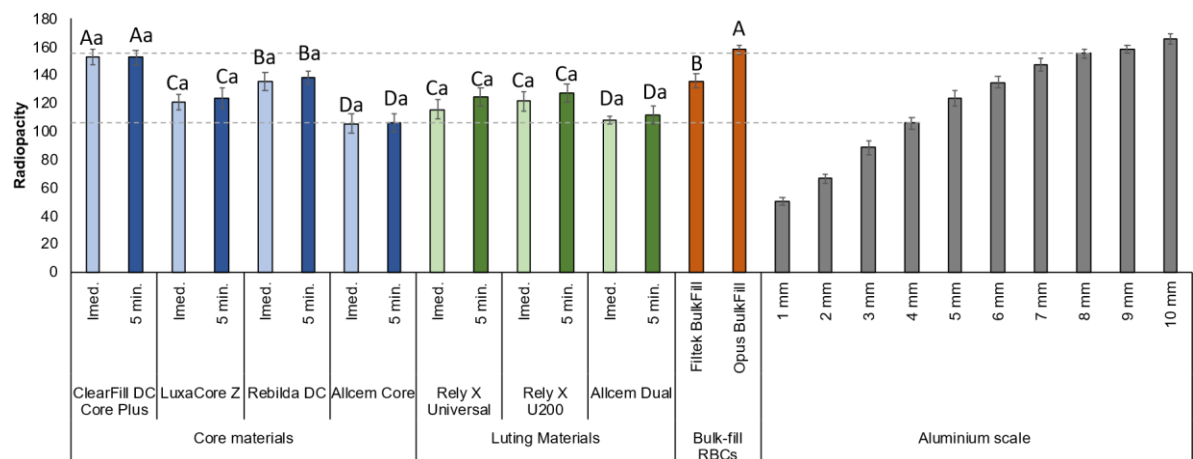


Figure 10. Means and standard deviation of radiopacity values for resin-core materials, dual cure resin cements and bulk-fill RBCs; upper case letter used for comparison between materials for each light activation protocol; and lower case letter used for comparison between light activation protocol for each resin-based material.

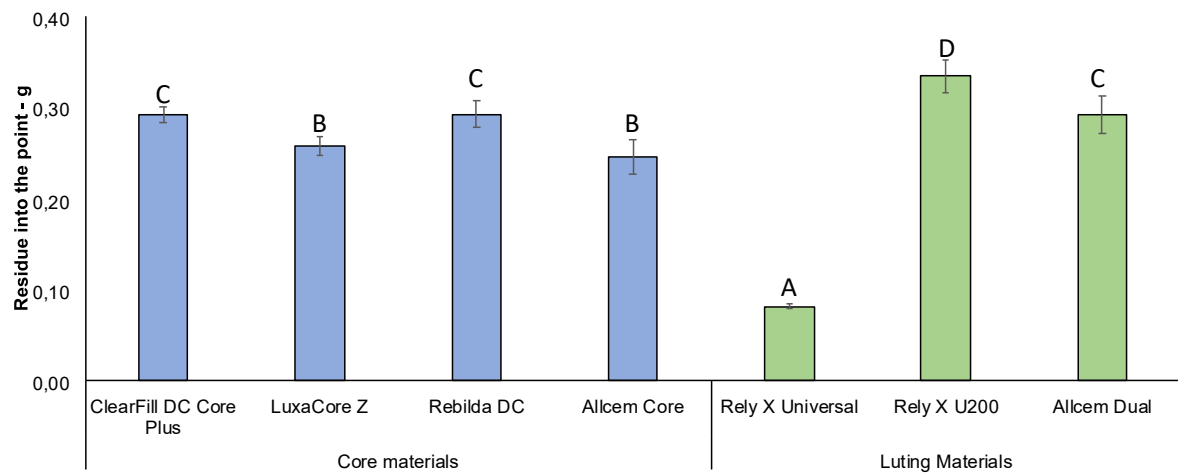


Figure 11. Means and standard deviation of residue into the point values (g) for resin-core materials and dual-cure resin cements. Different letters mean significant difference; upper caser letter used for comparison between materials for each light activation protocol; and lower caser letter used for comparison between light activation protocol for each resin-based material.

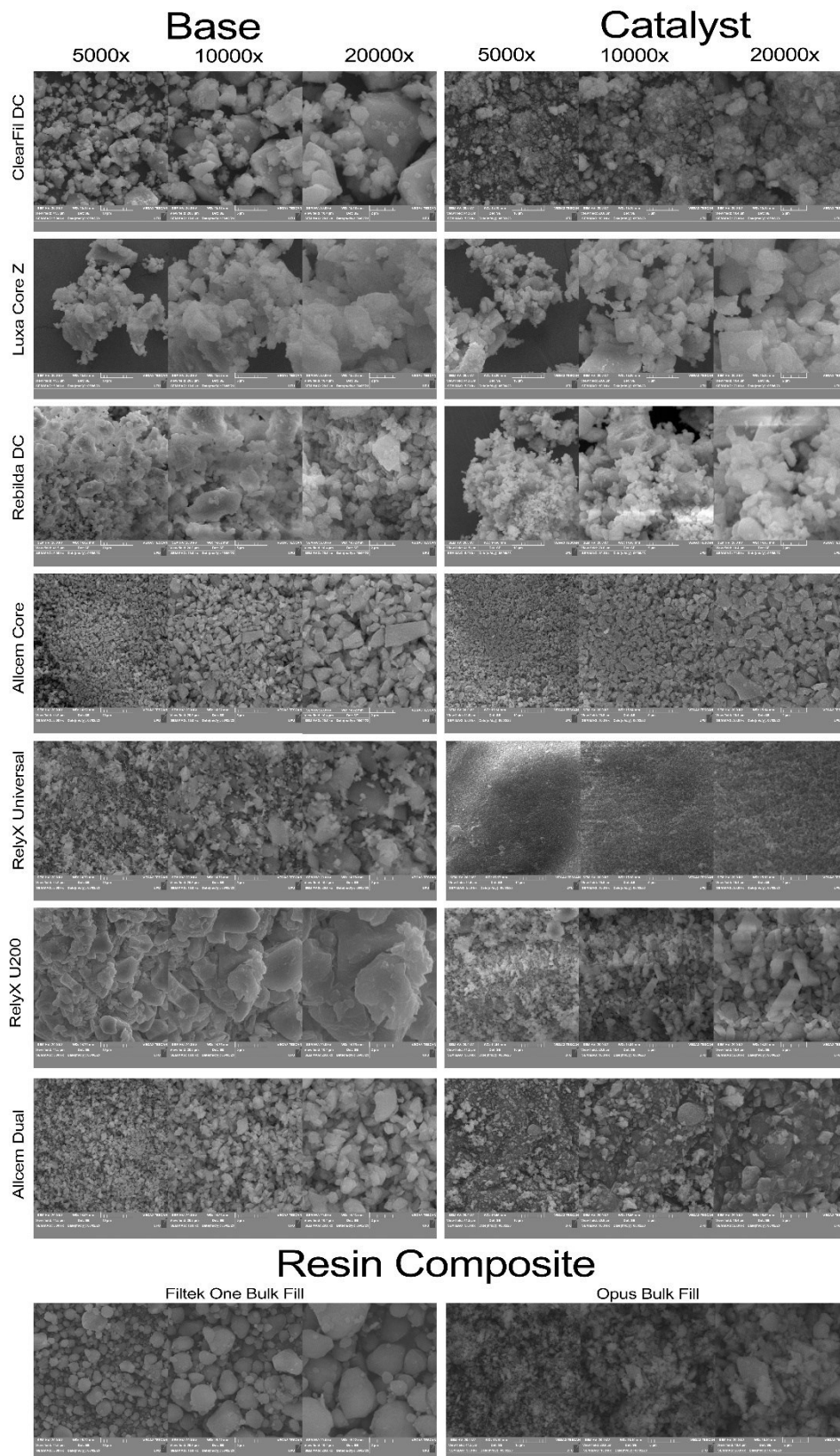


Figure 12. Scanning electron microscopy of filler content in the resin-core materials, dual-cure resin cements, and bulk-fill RBCs. Images with 5000, 10000 and 20000 $\times$ magnification.

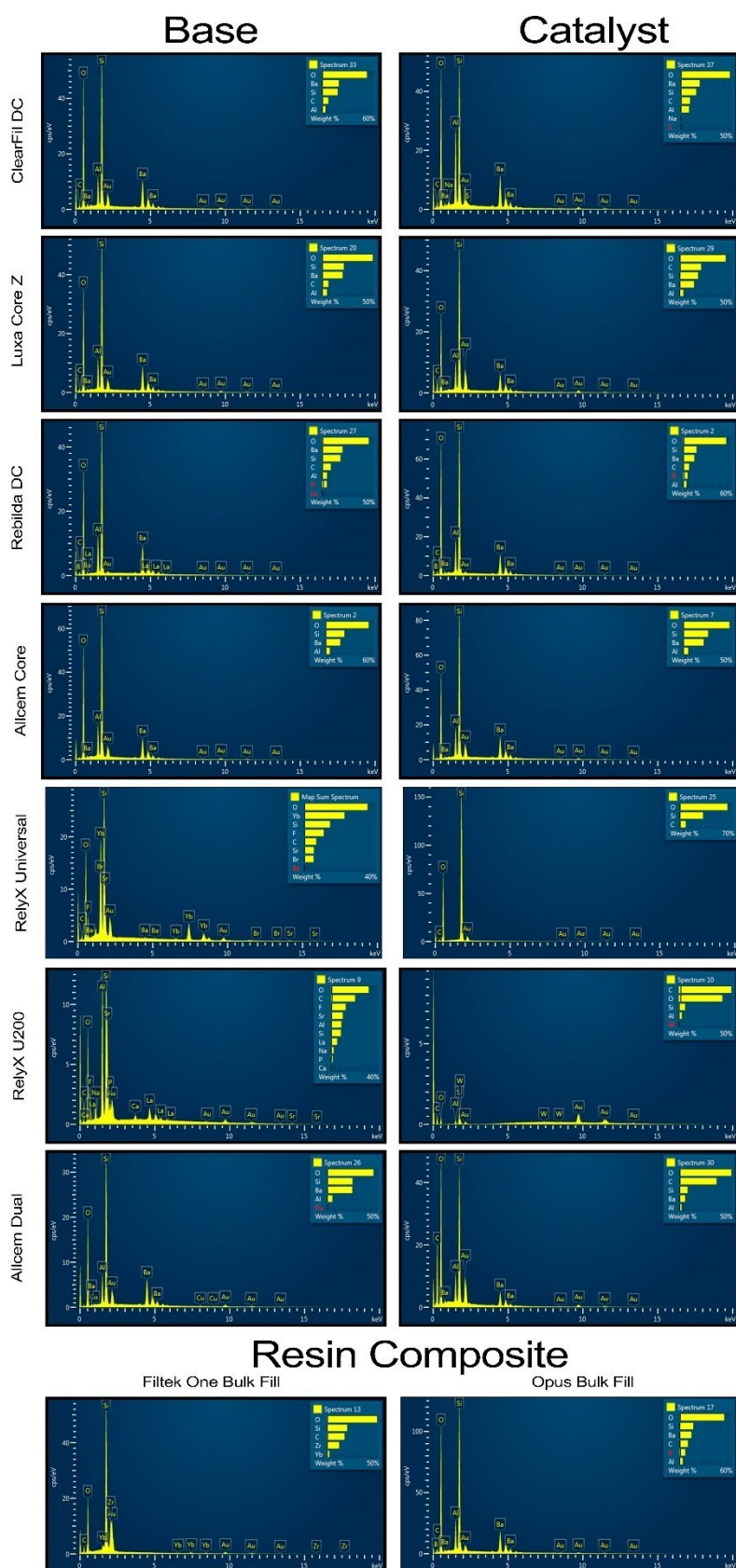


Figure 13. Energy dispersive spectroscopic analysis of the filler particles of resin-core materials, dual-cure resin cements, and bulk-fill RBCs.

CONSIDERAÇÕES GERAIS

Neste estudo verificou-se que a fotoativação tardia aguardando 5-minutos após a manipulação de resinas compostas “core” de dupla ativação reduziu significativamente a contração de polimerização pós-gel, da mesma forma que mostrado anteriormente em cimentos resinosos de dupla ativação. A fotoativação tardia, no geral, manteve ou melhorou ligeiramente as mesmas propriedades físicas e mecânicas sem influenciar negativamente esse comportamento para nenhum dos materiais testados. Com isso recomenda-se que esse protocolo deve ser incorporado na prática clínica para minimizar tensões de contração, podendo gerar interface adesiva mais estável e com distribuição de tensões mais homogêneas.

As resinas compostas “core” de dupla ativação exibiram propriedades físicas mecânicas similares ou superiores aos cimentos resinosos de dupla ativação. Destaca-se a efetiva fotoativação destes materiais em áreas profundas, o que suporta a possibilidade de seu uso para cimentar pinos de fibra de vidro em dentes tratados endodonticamente. Da mesma forma, as resinas compostas “core” de dupla ativação, apresentaram nesse estudo propriedades físicas e mecânicas similares ou superiores as resinas compostas bulk-fill.

Os resultados desse estudo mostram ainda que produtos desenvolvidos no mercado nacional apresentam desempenho físico e mecânico compatíveis com produtos líderes de mercado mundial. O clínico deve estar atendo ao custo dos produtos e buscar aquele produto que melhor se adapta e construir uma relação de fidelidade que faz com que o conhecimento e domínio da técnica potencialize o melhor a ser entregue pelo material de escolha. O uso de pontas misturadoras é mais que uma facilidade, é uma necessidade para que o material seja homogeneizado de forma adequada. A variação de resíduo de massa de cimento nas pontas misturadoras (2,2 – 5,8 %) ressalta a necessidade de se considerar, sempre que possível, a realização de mais de um dente em uma mesma sessão para que seja melhorada a eficiência do produto selecionado.

Os resultados comparativos entre às resinas compostas bulk-fill e as resinas compostas “core” suportam ainda o uso desses produtos na reconstrução coronária. Portanto, os resultados desse estudo in vitro, suportam as indicações clínicas reportadas pelos fabricantes de uso desses produtos para reabilitação de dentes tratados endodonticamente. A cimentação de pinos de fibra de vidro e restauração final e reconstrução de núcleos com um mesmo material, pode economizar tempo clínico e ao

mesmo tempo reduzindo diferentes interfaces entre diversos materiais, garantindo adesão estável e resistência desejada.

REFERÊNCIAS

- de Kuijper MCFM, Cune MS, Özcan M, Gresnigt MMM. Clinical performance of direct composite resin versus indirect restorations on endodontically treated posterior teeth: A systematic review and meta-analysis. *J Prosthet Dent*. 2021:S0022-3913(21)00634-X. <https://doi.org/10.1016/j.prosdent.2021.11.009>
- Ferrari M, Pontoriero DIK, Ferrari Cagidiaco E, Carboncini F. Restorative difficulty evaluation system of endodontically treated teeth. *J Esthet Restor Dent*. 2022;34(1):65-80. <https://doi.org/10.1111/jerd.12880>
- Kumar SS, Viswanathan M, Rajkumar K, Marudhamani C, Rajaganeshan VS, Biju KA. Comparative Study on Fracture Resistance of Endodontically Treated Tooth in Relation to Variable Ferrule Heights Using Custom-made and Prefabricated Post and Core: An In Vitro Study. *J Pharm Bioallied Sci*. 2020;12. https://doi.org/10.4103/jpbs.JPBS_166_20
- Barcelos LM, Bicalho AA, Verissimo C, Rodrigues MP, Soares CJ. Stress Distribution, Tooth Remaining Strain, and Fracture Resistance of Endodontically Treated Molars Restored Without or With One or Two Fiberglass Posts and Direct Composite Resin. *Oper Dent*. 2017;42(6):646-657. <https://doi.org/10.2341/16-224-L>
- Nahar R, Mishra SK, Chowdhary R. Evaluation of stress distribution in an endodontically treated tooth restored with four different post systems and two different crowns- A finite element analysis. *J Oral Biol Craniofac Res*. 2020;10(4):719-726. <https://doi.org/10.1016/j.jobcr.2020.10.004>
- Pereira RD, Valdívia AD, Bicalho AA, Franco SD, Tantbirojn D, Versluis A, Soares CJ. Effect of Photoactivation Timing on the Mechanical Properties of Resin Cements and Bond Strength of Fiberglass Post to Root Dentin. *Oper Dent*. 2015;40(5):E206-21. <https://doi.org/10.2341/14-115-L>
- Price RB, Ferracane JL, Hickel R and Sullivan B. The light-curing unit: An essential piece of dental equipment. *International Dental Journal*. 2020;70(6):407-417. Reis JMDSN, Oliveira CRM, Reis EGJ, Mascaro BA, Abi-Rached FO. One-step fiber post cementation and core build-up in endodontically treated tooth: A clinical case report. *J Esthet Restor Dent*. 2020;32(1):5-11. <https://doi.org/10.1111/idj.12582>
- Senn LF, Lazos JP and Brunotto M. Assessment of maxillary central incisor crown form. *The International journal of periodontics & restorative dentistry*. 2013;33 (3):347-353. <https://doi.org/10.11607/prd.1206>

- Säilynoja E, Garoushi S, Vallittu PK, Lassila L. Characterization of Experimental ShortFiber-Reinforced Dual-Cure Core Build-Up Resin Composites. *Polymers (Basel)*. 2021;13(14):2281. <https://doi.org/10.3390/polym13142281>
- Soares CJ, Braga S, Price RB. Relationship Between the Cost of 12 Light-curing Units and Their Radiant Power, Emission Spectrum, Radiant Exitance, and Beam Profile. *Oper Dent*. 2021;46(3):283-292. <https://doi.org/10.2341/19-274-L>
- Skupien JA, Cenci MS, Opdam NJ, Kreulen CM, Huysmans MC, Pereira-Cenci T. Crown vs. composite for post-retained restorations: A randomized clinical trial. *J Dent*. 2016;48:34-9. <https://doi.org/10.1016/j.jdent.2016.03.007>
- Lassila L. Characterization of Experimental Short-Fiber-Reinforced Dual-Cure Core Build-Up Resin Composites. *Polymers (Basel)*. 2021;13(14):2281. <https://doi.org/10.3390/polym13142281>
- Soares CJ, Rodrigues MP, Faria-E-Silva AL, Santos-Filho PCF, Veríssimo C, Kim HC, Versluis A. How biomechanics can affect the endodontic treated teeth and their restorative procedures? *Braz Oral Res*. 2018;32(suppl 1):e76. <https://doi.org/10.1590/1807-3107bor-2018.vol32.0076>
- Soares PM, Morgan LF, Tonelli SQ, Limeira FI, Bruzinga FF, Seraidarian PI, Albuquerque RC, Silveira FF. Effect of Different Resin Cements on the Bond Strength of Custom-made Reinforced Glass Fiber Posts-A Push-out Study. *J Contemp Dent Pract*. 2021;22(3):219-223. <https://doi.org/10.5005/jp-journals-10024-3058>